

N72-26968

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A SWIRL-CAN COMBUSTOR  
AT IDLE CONDITIONS

by Richard W. Niedzwiecki, Arthur M. Trout,  
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Lewis Research Center  
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1972

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1. Report No. <b>NASA TM X-2578</b>	2. Government Accession No.	3. Recipient's Catalog No.		
4. Title and Subtitle <b>PERFORMANCE OF A SWIRL-CAN COMBUSTOR AT IDLE CONDITIONS</b>		5. Report Date <b>June 1972</b>		
6. Performing Organization Code				
7. Author(s) <b>Richard W. Niedzwiecki, Arthur M. Trout, and Edward Mularz</b>		8. Performing Organization Report No. <b>E-6892</b>		
9. Performing Organization Name and Address <b>Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135</b>		10. Work Unit No. <b>764-74</b>		
11. Contract or Grant No.				
12. Sponsoring Agency Name and Address <b>National Aeronautics and Space Administration Washington, D.C. 20546</b>		13. Type of Report and Period Covered <b>Technical Memorandum</b>		
14. Sponsoring Agency Code				
15. Supplementary Notes				
16. Abstract Test results of a full annulus swirl-can combustor operated at simulated engine idle conditions indicated that significant improvements in combustion efficiency and accompanying reductions in pollutants could be realized with radial scheduling of fuel. Test conditions were an inlet air temperature of 478 K (400° F), a pressure of 4 atmospheres, and a reference velocity of 26 meters per second (85 ft/sec). At a fuel-air ratio of 0.008, radial scheduling of fuel increased combustion efficiency from less than 50 percent with no scheduling to nearly 100 percent and produced emission index values of unburned hydrocarbons and carbon monoxide of 10 and 40, respectively.				
17. Key Words (Suggested by Author(s)) <b>Combustor                      Pollution Combustion                      Idle conditions Modular combustor</b>		18. Distribution Statement <b>Unclassified - unlimited</b>		
19. Security Classif. (of this report) <b>Unclassified</b>		20. Security Classif. (of this page) <b>Unclassified</b>	21. No. of Pages <b>11</b>	22. Price* <b>\$3.00</b>

# PERFORMANCE OF A SWIRL-CAN COMBUSTOR AT IDLE CONDITIONS

by Richard W. Niedzwiecki, Arthur M. Trout, and Edward Mularz

Lewis Research Center

## SUMMARY

Test results of a full annulus swirl-can combustor operated at simulated engine idle conditions indicated that significant improvements in combustion efficiency and accompanying reductions in pollutants could be realized with radial scheduling of fuel. Test conditions were an inlet air temperature of 478 K (400° F), a pressure of 4 atmospheres, and a reference velocity of 26 meters per second (85 ft/sec).

Radial scheduling of fuel increased fuel-air ratios for localized zones within the combustor by supplying all the fuel to only one of three circumferential swirl-can rows. With fuel supplied to all the swirl cans, combustion efficiencies were less than 50 percent, and blowout occurred at a fuel-air ratio of 0.008. With fuel supplied to only the inner swirl-can row, combustion efficiencies increased to nearly 100 percent and produced unburned hydrocarbon and carbon monoxide emission index values of 10 and 40, respectively.

## INTRODUCTION

This report describes a method of improving idle combustion efficiency for a full-annulus swirl-can primary combustor and thereby reducing pollutant levels. Major sources of pollution in the vicinity of airports are unburned hydrocarbons and carbon monoxide formed during engine idle and taxiing (ref. 1). These pollutants are symptoms of poor combustion efficiencies resulting from the low fuel-air ratios, low inlet air temperatures and pressures, and poor fuel atomization encountered during idle operation.

Several methods have been proposed for reducing pollutant levels of conventional combustors at idle conditions. These methods require a control device which would be employed during idle conditions and not used for takeoff and cruise. One of these, reported in reference 2, utilized air-assist fuel nozzles to improve fuel atomization. Other approaches attempt to increase combustion efficiencies at idle conditions by reducing flow velocities through combustor primary zones. Several proposed techniques for

accomplishing this include a variable geometry combustor and the use of a diffuser bleed system such as that described in reference 3. In addition, idle pollutants could be reduced by bleeding a disproportionately large amount of air from the compressor.

The investigation described in this report was conducted on a combustor in which the fuel was injected into 120 swirl-cans. These swirl-cans were divided into three radial rows containing 32, 40, and 48 modules. The method investigated for improving combustion efficiency at idle conditions was to vary the radial scheduling of fuel between the three rows of swirl cans. Test results are presented for all of the swirl-cans fired with fuel and with only the inner, center, or outer module row fired. Test conditions were a fuel-air ratio range of 0.006 to 0.022, a reference velocity of 26 meters per second (85 ft/sec), and inlet air temperatures and pressures of 478 K (400° F) and 4 atmospheres, respectively.

## APPROACH

Two methods have been developed for overcoming the efficiency falloff at low fuel-air ratios for swirl-can combustors. The first method applies to combustors required to operate in a low to intermediate exit temperature range, possibly to 1450 K (2200° F), and involves reducing the swirler flow area and thereby reducing airflow through the swirl-cans. Effects of swirler area reductions and their effect on improving combustion efficiency at lower fuel-air ratios are reported in reference 4. Thus, proper sizing of swirler flow area to combustor requirements can be used to improve performance at low fuel-air ratios.

The second method applies to combustors required to operate from low fuel-air ratios to stoichiometric conditions and was employed for these tests. These tests utilized a modified version of the combustor reported in reference 5. This combustor was designed for and successfully operated at fuel-air ratios in excess of stoichiometric. Its operation at idle conditions, where a fuel-air ratio of 0.008 is required, was a particularly stern test since it required an operational fuel flow range 2.5 to 3 times greater than that encountered by more conventional combustors. The second method involves supplying fuel to all the swirl-cans for high-temperature operation and to only one of three circumferential swirl-can rows for idle operation. Scheduling of fuel in this manner increases the fuel loading for each fired module and thereby increases localized fuel-air ratios while maintaining burning around the entire circumference of the combustor.

## COMBUSTOR DESIGN

The test combustor is shown in figures 1 and 2. The combustor is an annular design 0.514 meter (20.25 in.) long and 1.067 meters (42 in.) in diameter and incorporates a combustor module array consisting of 120 swirl-can modules which distribute combustion uniformly across the annulus. The modules are arranged in three concentric rows with fuel flow independently controlled to each row. There are 48 modules in the outer row, 40 in the center row, and 32 in the inner row.

## MODULE DESIGN

The combustor module design is shown in figure 3. Each module premixes fuel with air in the carburetor, swirls the mixture, stabilizes combustion in its wake, and provides interfacial mixing areas between the bypass air through the array and the hot gases in the wake of the module. Two flame stabilizer designs were used in order to tailor combustor exit temperature profiles. The outer and inner module rows used flame stabilizer A, and the center module row used the reduced blockage flame stabilizer B.

## TEST PROCEDURE AND INSTRUMENTATION

Tests were conducted in the closed duct facility described in reference 6. A three-point, water-cooled gas sampling probe, shown in figure 4, was used to obtain combustor exhaust gas samples. Samples were withdrawn from one circumferential location at the combustor exit. Nitric oxide concentrations were measured by an on-line nondispersive infrared recorder (NDIR). Unburned hydrocarbons, carbon monoxide, and carbon dioxide concentrations were determined from batch samples. A flame ionization detector was used to determine unburned hydrocarbon concentrations. A gas chromatograph was used to determine quantities of carbon monoxide and carbon dioxide.

Since practical considerations limited exhaust gas sampling to only one circumferential location, attempts were made to verify that the gas sampling position was representative of pollutant levels at the combustor exit. Concentrations of carbon dioxide, carbon monoxide, and unburned hydrocarbons were used to calculate a combustor fuel-air ratio. This ratio, when compared to fuel-air ratios determined from metered values of air flow and fuel flow, showed a deviation of less than 5 percent.

Combustion efficiency was defined as the ratio of the measured temperature rise across the combustor to the theoretical temperature rise. The theoretical rise was calculated from the metered fuel-air ratio, fuel properties, and inlet air temperature, pressure, and water vapor concentrations. The combustor exit temperatures were

measured with five-point traversing aspirated thermocouple probes and were mass-weighted for the efficiency calculation; 585 exit temperatures were used for each mass-weighted average.

## TEST RESULTS

Since the combustor was designed for high exit temperature operation, it is not surprising that a falloff of combustion efficiency, with corresponding increases in pollutant levels, occurs at low fuel-air ratios. The extent of this problem can be seen from the top curve of figure 5. As the combustor exit temperature decreases, there is a notable rise in the unburned hydrocarbon emission index.

Effects of fuel scheduling can be seen from the bottom curve of figure 5. The number of fired modules was reduced from 120 to 104 by shutting off the fuel to one-half of the inner module row. Emission index values were decreased from 30 to 60 percent for equivalent combustor exit temperatures with the greatest percentage decreases occurring at the highest combustor exit temperatures.

The combustor was tested at idle conditions with all of the modules supplied with fuel and also with each of the three module rows individually supplied with all the fuel. The test conditions were a combustor reference velocity of 26 meters per second (85 ft/sec) and an inlet air temperature and pressure of 478 K (400° F) and 4 atmospheres, respectively.

### Combustion Efficiency

Combustion efficiency results are presented in figure 6. Fuel-air ratios represent overall values and represent all the air and fuel supplied to the combustor. With all the modules supplied with fuel, combustion efficiencies were low and blowout occurred at a fuel-air ratio of about 0.009. Supplying all the fuel to the center module row improved combustion efficiency somewhat but produced an efficiency of only 50 percent at a fuel-air ratio of 0.008. Supplying all the fuel to the outer module row increased combustion efficiency significantly. Supplying all the fuel to the inner module row raised the combustion efficiency to nearly 100 percent.

Effects of fuel scheduling were greatest for the inner module row, since this row contained the lowest number of modules, and thus each module was supplied with proportionately more fuel for a given overall fuel-air ratio. The reason that scheduling fuel to the center module row produced only a small improvement in combustion efficiency was probably due to quenching resulting from the reduced blockage flame stabilizers that this

row contained. The reduced blockage caused a proportionately larger amount of air to flow through the center of the array.

## Unburned Hydrocarbons and Carbon Monoxide

Emission index values for unburned hydrocarbons and carbon monoxide are shown in figures 7 and 8, respectively. Both pollutants followed inversely the same trends as combustion efficiency. A further indication of quenching of the center module row is shown in figure 8, which shows carbon monoxide levels were higher for the center module row than when all the modules were supplied with fuel.

The lowest emission index values occurred with only the inner module row supplied with fuel. At a fuel-air ratio of 0.008 the emission index values were approximately 10 for hydrocarbons and 40 for carbon monoxide. Nitrogen dioxide concentrations were low and did not exceed an emission index value of 1.

## SUMMARY OF RESULTS

Performance of a full annulus swirl-can combustor was evaluated at simulated engine idle conditions. Test conditions were an inlet air temperature of 478 K (400° F), a pressure of 4 atmospheres, and a reference velocity of 26 meters per second (85 ft/sec).

Significant improvements in combustion efficiency and accompanying reductions in pollutants were realized by radial scheduling of fuel flow. The following results were obtained at a fuel-air ratio of 0.008:

1. With all the swirl-cans supplied with fuel blowout occurred. Combustion efficiencies were approximately 50 percent at a fuel-air ratio of 0.01.
2. With all the fuel supplied to the center module row, only a small improvement in performance resulted because of quenching effects. The combustion efficiency was 50 percent.
3. With all the fuel supplied to the outer module row, combustion efficiency increased significantly to 86 percent. Pollutant levels were also correspondingly lowered.
4. Best results were obtained when all the fuel was supplied to the inner module row. Combustion efficiencies near 100 percent were obtained. Unburned hydrocarbon and carbon monoxide emission index values were 10 and 40, respectively.

Lewis Research Center,  
National Aeronautics and Space Administration,  
Cleveland, Ohio, April 11, 1972,  
764-74.

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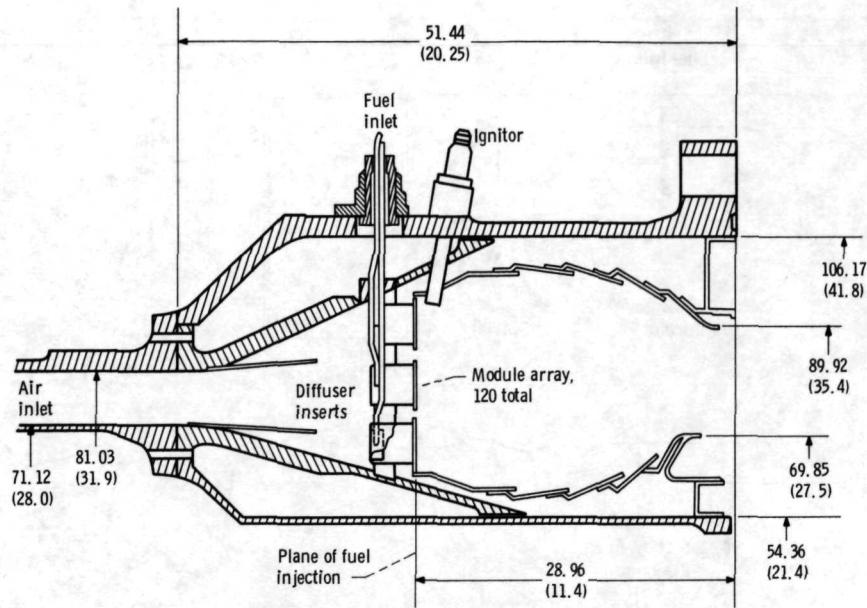


Figure 1. - Full annular model of high-temperature combustor. (Dimensions in centimeters (in.).)

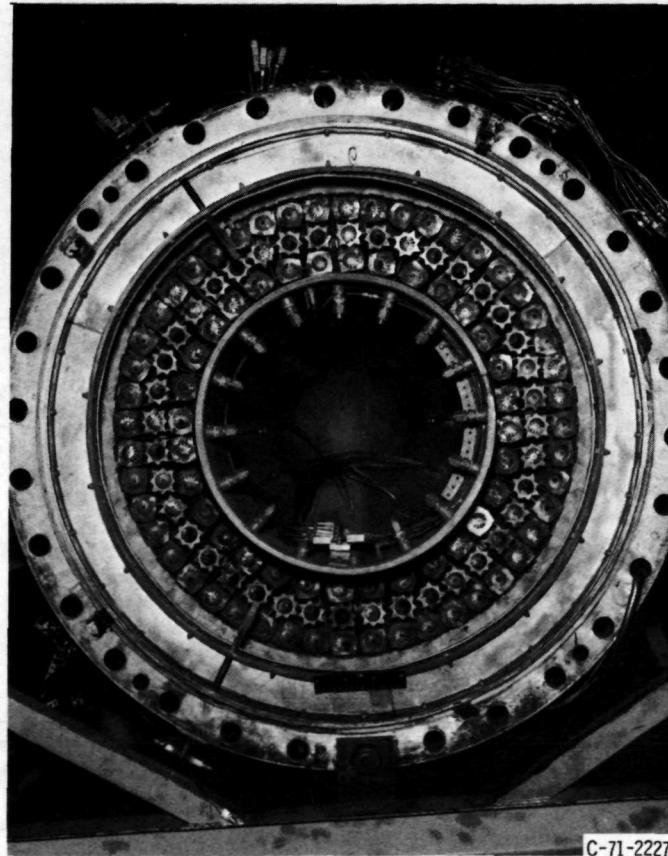


Figure 2. - Combustor with inside-diameter liner removed to better illustrate module array. View is upstream into the combustor.

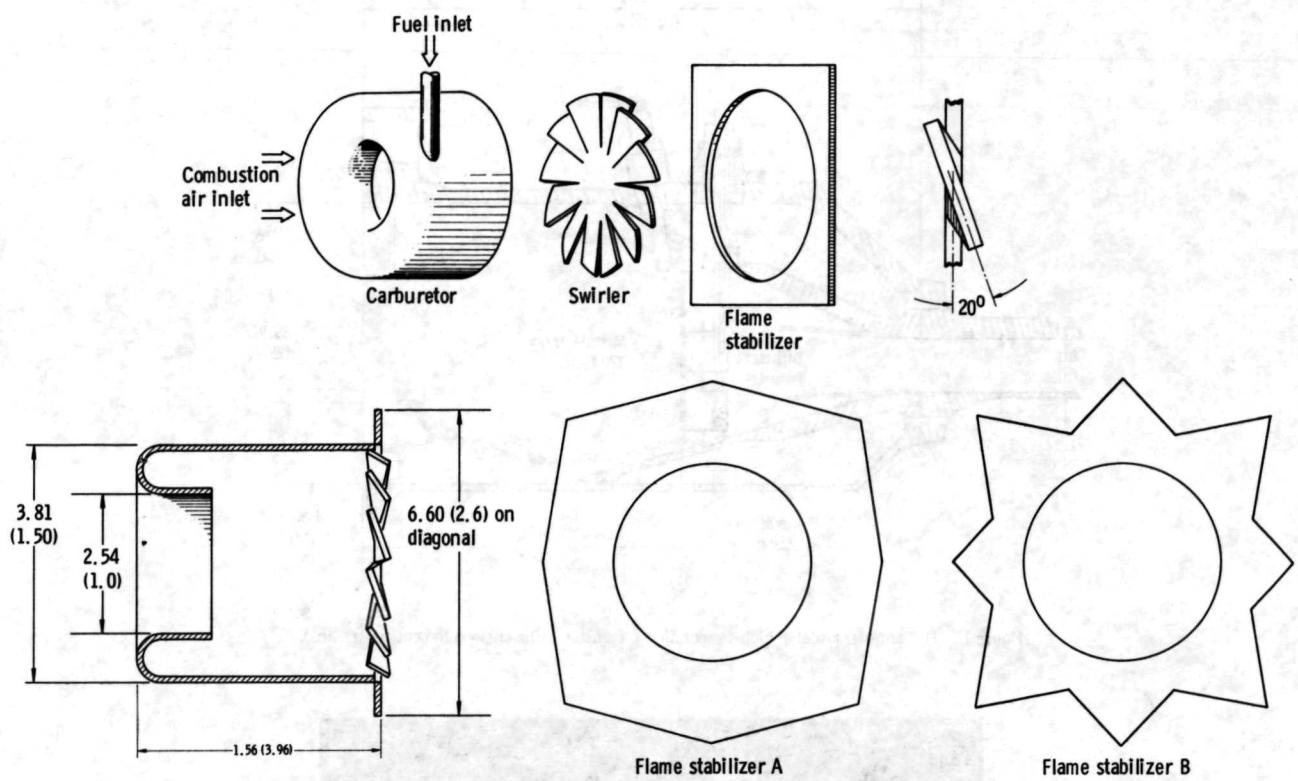


Figure 3. - Combustor module details. (Dimensions in centimeters (in.).)

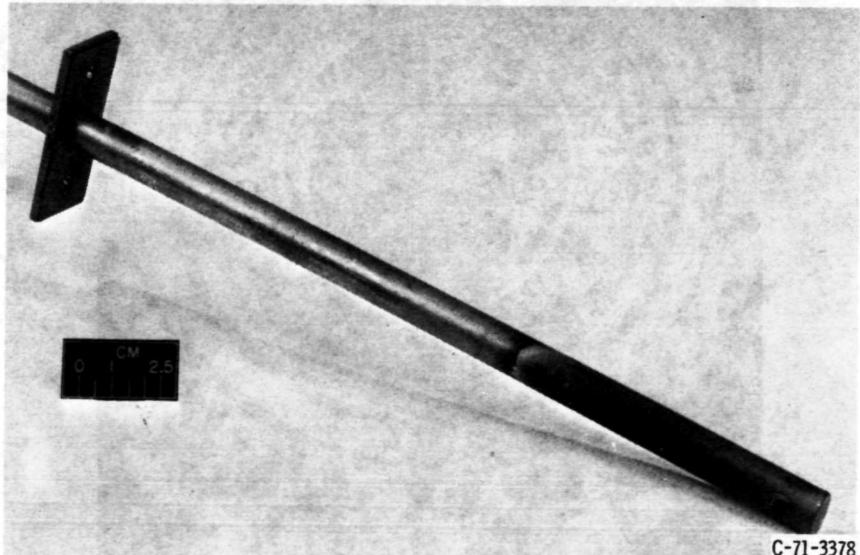


Figure 4. - Three-point gas sampling probe with water-cooled jacket.

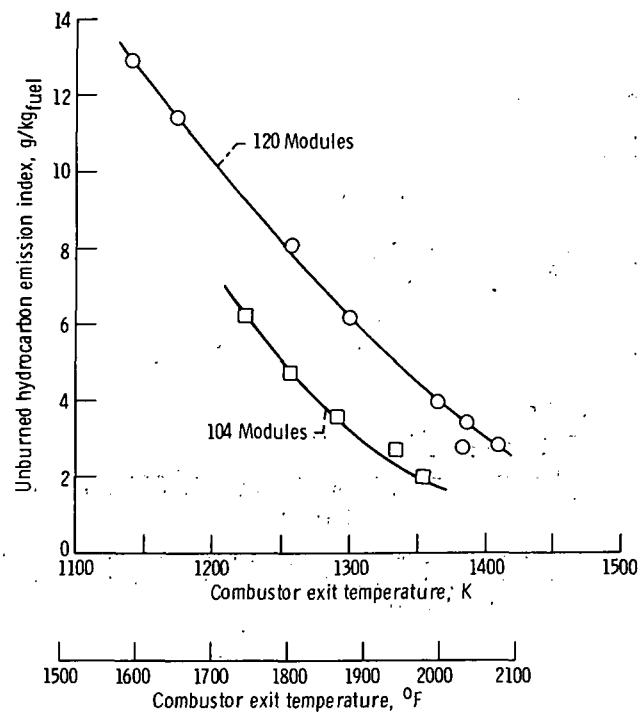


Figure 5. - Module number effect. Inlet air temperature, 589 K (600° F); inlet air pressure, 6 atmospheres; reference velocity, 26 meters per second (85 ft/sec).

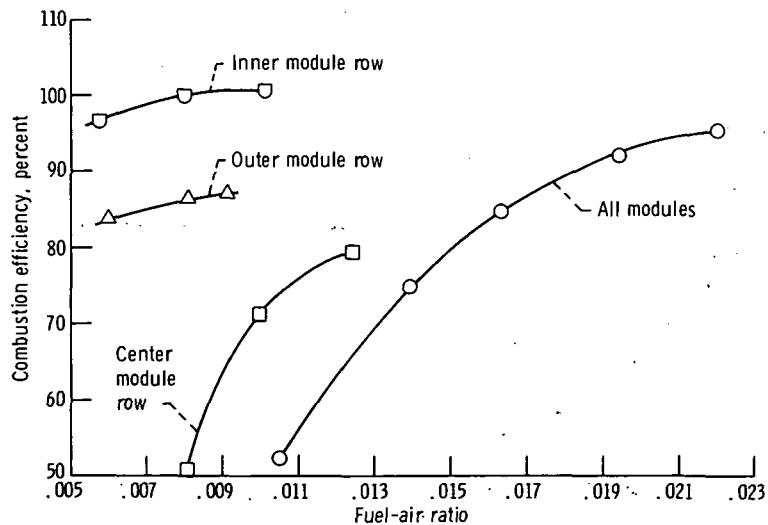


Figure 6. - Combustion efficiency during idle tests. Inlet air temperature, 478 K (400° F); inlet air pressure, 4 atmospheres; reference velocity, 26 meters per second (85 ft/sec).

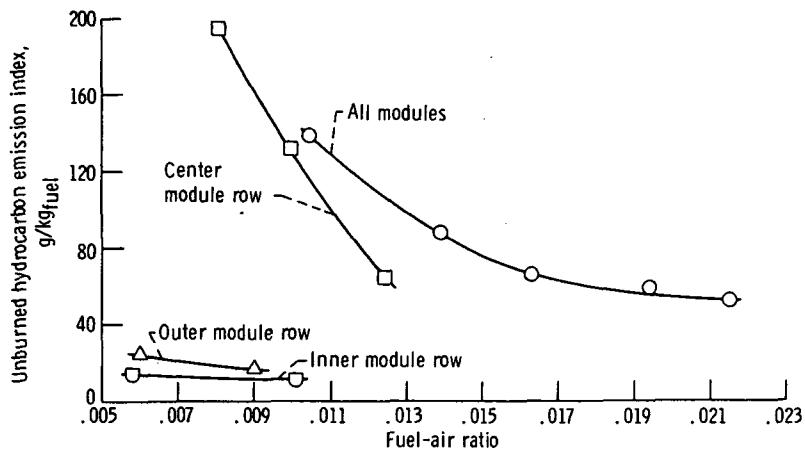


Figure 7. - Unburned hydrocarbon emissions during idle tests. Inlet air temperature, 478 K (400° F); inlet air pressure, 4 atmospheres; reference velocity, 26 meters per second (85 ft/sec).

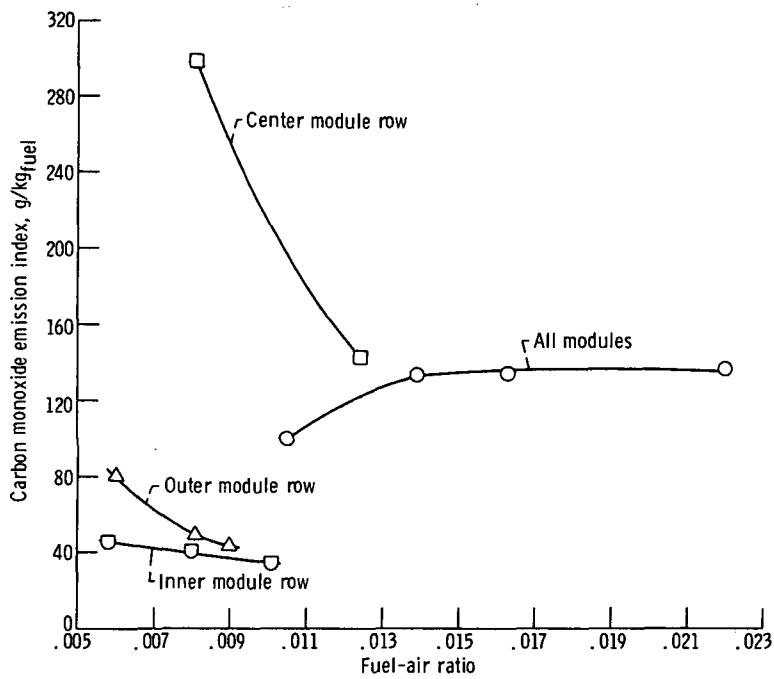


Figure 8. - Carbon monoxide emissions during idle tests. Inlet air temperature, 478 K (400° F); inlet air pressure, 4 atmospheres; reference velocity, 26 meters per second (85 ft/sec).

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— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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